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(54) CONTROLLING X-RAY SOURCES

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method and apparatus for controlling the magnitude of a steady voltage and a steady current to be applied to an X-ray tube for a proposed exposure duration, said X-ray tube having a given limiting boundary to the permissible operating magnitudes of a steady applied voltage and a steady current in respect of a given switch-on duration, in which an X-ray exposure meter is used to determine the current-time product required to provide a desired quantity of radiation, i.e. dose or radiographic exposure density, during said proposed exposure duration.

Such control has hitherto usually been performed by skilled personnel having considerable experience in radiography.

It is an object of the invention to provide an improved method and apparatus which can be supervised satisfactorily by an operator with less skill or experience.

According to the invention there is provided a method of controlling the magnitude of a steady voltage and a steady current applied to an X-ray tube to provide a proposed dose or radiographic exposure density as a result of a proposed exposure duration, comprising the steps of applying to the X-ray tube during a predetermined test period a respective predetermined test voltage and test current within the working limits of the X-ray tube for the test period and measuring the dose or exposure value by means of an X-ray exposure meter arranged to derive therefrom a corresponding related tube operating current which together with said test voltage would provide said proposed dose or radiographic exposure density during said proposed exposure duration, mechanically or electrically forming a first function relating respective magnitudes representing a range of tube voltages and corresponding tube currents required substantially to provide said proposed dose or radiographic exposure density during said proposed exposure duration and including said test voltage and corresponding related tube operating current, mechanically or electrically forming a second function correspondingly relating respective magnitudes representing the range of tube voltages and corresponding tube currents which defines the limiting boundary of the permissible operating region of said X-ray tube for said proposed exposure duration, mechanically or electrically relating corresponding magnitudes generated by said first function and said second function to provide respective magnitudes corresponding to the lower value of the tube voltage for which said functions coincide and the corresponding tube current, and controlling the tube voltage and the tube current in correspondence therewith during a proposed exposure, or controlling the tube voltage in preparation for a further exposure determination.

The corresponding magnitudes representing the X-ray tube current can be made proportional to the logarithm of the tube current and said first function can be caused to include the values representing the test voltage and the corresponding related tube operating current which together would provide the proposed dose or radiographic exposure density during the proposed exposure duration, by applying a corresponding shift to that magnitude representing the logarithm of the tube current.

The X-ray exposure measurement is initially made at a test voltage which in general differs significantly from the lower limit voltage determined by the method. The first function relating voltage with current to provide the same dose for a given exposure time has to be defined for an average subject and in practice some departure will be found from the relative transparency or absorption in respect of X-rays produced at different tube voltages which is assumed in defining the first function, and this can give rise to errors. For this

reason a further exposure measurement can be made by means of the X-ray exposure meter while applying the determined lower value of the tube voltage for which the first and second functions coincided as a result of the previous measurement, together with the test current to the X-ray tube, and then repeating the other corresponding steps of the method to determine a further and more accurate said lower value of the tube voltage for which the first and second functions coincide, and the corresponding current.

According to an embodiment of the invention there is provided X-ray apparatus arranged to carry out the method claimed and including a first function generator arranged to generate said first function so that an input voltage representing a proposed X-ray tube voltage gives rise to a first output signal in the form of a voltage linearly representing the logarithm of the corresponding X-ray tube current, a second function generator arranged to generate said second function so that an input voltage representing a proposed X-ray tube voltage gives rise to a second output signal in the form of a voltage linearly representing the logarithm of the corresponding limiting X-ray tube current, an X-ray exposure meter having means for sensing X-radiation after passing through an object to be radiographed and resulting from the application of a test voltage and a test current to the X-ray tube for a test period, and a circuit arranged to determine from the sensed radiation the X-ray tube current required to carry out a proposed exposure at the test voltage for a proposed exposure time and to provide a third output signal in the form of a voltage linearly representing the logarithm of the X-ray tube current so determined, a clamping circuit having a signal input to which said first output signal is supplied and a clamping input arranged to clamp the output voltage to a zero reference during a said X-ray exposure measurement, and summation means arranged to form an output voltage by summation of said second and third output signals and the output signal of said clamping circuit, the output of said summation means being applied as the input voltage to said first and second function generators and as a control input signal to a voltage control circuit for the X-ray tube, the arrangement being such that after the completion of said X-ray exposure measurement, the output of said summation means comprises a voltage which represents the lower value of the X-ray tube voltage for which said first and second functions coincide.

$\log I_t = V$

Storage means can be provided coupled to the output of the summation means to store the output signal of the summation means and thereby to maintain the application of said output signal to the inputs of the first and second function generators and to the X-ray tube voltage control circuit and a change over switch can be arranged to control the input of an X-ray tube current control circuit so that during an X-ray exposure measurement a predetermined test current is applied to the X-ray tube and after the completion of that measurement the second output signal is employed to cause the current applied to the X-ray tube to take up the magnitude of the limiting current which corresponds to the said determined lower value of the X-ray tube voltage.

Means can be provided for disconnecting the storage means from the output of the summation means during a first said exposure measurement and for feeding to the said storage means when thus disconnected, a voltage representing the test voltage to be used during said first exposure measurement.

According to a further embodiment of the invention there is provided X-ray apparatus arranged to carry out the method claimed and including an X-ray tube, means for controlling the tube voltage and tube current of said X-ray tube, an X-ray exposure meter having X-radiation sensing means disposed behind the object to be radiographed and arranged during a test period in which the X-ray tube is energised by a test voltage and a test current within the working limits of the X-ray tube for said test period, to provide an indication of the tube current required at said test voltage to provide a proposed dose or radiographic exposure density after a proposed exposure duration, and a current-scale ruler and jig assembly comprising a current-scale ruler representing the logarithm of the tube current, and associated with a limiting boundary curve representing said second function, and a jig arranged for displacement relative to said current-scale ruler in a direction parallel to the ruler representing the logarithm of the tube current, said jig carrying a curve substantially representing said first function the arrangement being such that said jig can be set so that said curve passes through a point corresponding to the test voltage and the corresponding said tube current indicated by said X-ray exposure meter and the lower value of the tube voltage at which the two curves intersect and the corresponding tube current can be read from the scale.

In order that the invention may be clearly understood and readily carried into effect, embodiments thereof will now be described by way of example, with reference to the accompanying drawings, of which:—

Fig. 1 shows a voltage-current characteristic relating to the operation of an X-ray tube in explanation of an embodiment of the invention,

Fig. 2 illustrates by way of a block-schematic diagram a circuit arrangement of X-ray apparatus embodying the invention,

Fig. 3 illustrates by means of a block-

schematic diagram, an X-ray exposure meter which can form part of the circuit arrangement shown in Fig. 2, and

Fig. 4 shows by means of a block-schematic diagram, a clamping circuit and an adder and subtractor circuit which can form part of the circuit arrangement shown in Fig. 2.

Fig. 1 is a graph depicting a range of voltages and currents and relates to the operation of an X-ray tube. The X-ray tube emission current is depicted on a logarithmic scale denoted by log I on the vertical axis and the electron accelerating voltage is depicted along the horizontal axis and denoted by V.

The reference numeral 1 denotes the limiting boundary to the operating range for a steady voltage and corresponding steady current applied to an X-ray tube for a predetermined switch-on duration to which the limits relate, and 2 and 3 denote curves each corresponding to a respective quantity of radiation, i.e. dose or radiographic exposure density relating to a photograph or radiographic film provided during a said predetermined duration of an exposure for radiography or for observation purposes obtained by irradiation of an object.

The limiting boundary of the operating range 1 of the X-ray tube gives the relationship between the maximum suitable X-ray tube current value and the corresponding selected voltage for energizing the X-ray tube for a given switch-on duration.

The principle of the method embodying the invention will be explained as follows. A given voltage V_{test} and a corresponding current I_{test} are applied to the X-ray tube for a predetermined switch-on duration, V_{test} and I_{test} lying well within the region of permissible values for said switch-on duration, and an exposure measurement is performed, following the above example, in a region under examination by an observation device and later to be exposed to a proposed dose of radiation. From this exposure measurement a current value I_{w_1} associated with the voltage V_{test} is determined which will yield a proposed dose or radiographic exposure density in a photograph or radiographic film after a proposed switch-on duration. In the case of a radiographic film or photograph the switch-on duration employed for the exposure measurement is made the same as that for the exposure measurement during fluoroscopy, whereas when a film exchanger is used these switch-on durations can be related by a predetermined ratio. Through the point in Fig. 1 corresponding to the proposed current value I_{w_1} and the given voltage value V_{test}, the curve 2 passes which represents a function connecting points with voltage and current values which would cause the same dose or radiographic exposure density as a result of the proposed switch-on duration. The curve 2 intersects the limiting operational boundary 1 at two points and the point representing the lower voltage value V_{min} and a corresponding current value I_1 is selected. This is the most suitable adjustment for the radiation source because when a maximum amount of control of the source is desired within a predetermined limiting boundary to the operational range, it is preferable to select the lowest possible voltage since this yields radiation which provides an optimum contrast for radiography.

The function relating voltage and current for a given dose or exposure density and switch-on duration, is computed for an average subject. In practice some subjects respond differently from the average to a variation in the hardness of the X-radiation brought about by a given change in the tube voltage. Thus in the case of a large difference between V_{test} and V_{min_1} it may happen that the radiographic exposure density provided by the values found for V_{min_1} and I_1 will depart slightly from the desired density. A subsequent exposure measurement would then be performed at the determined voltage value V_{min_1} again using the current I_{test}, and this could yield a further current value I_{w_2} slightly different from the current value I_1 originally found, but which may now lie outside the boundary 1. A constant dose or exposure density curve 3 associated with the voltage and current values V_{min_1}, I_{w_2} is provided which passes through that point, and the point of intersection V_{min_2} with the limit boundary curve 1 at the lower voltage point V_{min_2}, yields an associated value I_2 for the current which will then produce a more accurate approximation of the correct value for the proposed exposure. Although generally one or two exposure measurements will be sufficient this procedure may be repeated, if desired, until the values found for $I_{w_{n+1}}$ and I_n substantially coincide and this will generally be the case after three exposure measurements.

By using a logarithmic current scale the curve 3 may be obtained by shifting the curve 2 relative to the curve 1 and the system of axes in the vertical direction so that, with the aid of a jig moved along a current-scale ruler, the curve 2 can be made to pass in a simple manner through an arbitrary point, such as the point V_{test}, log I_{w_1}, so that the voltage and current values to which the X-ray tube is to be adjusted, namely V_{min_1}, log I_1, can be

determined very quickly and simply even by persons that are not very skilled in the art or have little experience in the use of X-ray equipment.

X-ray apparatus embodying the invention is illustrated schematically in Fig. 2. An X-ray source 5, comprising an X-ray tube is connected to a voltage control circuit 7 and a current control circuit 9 each having control signal inputs 11 and 13, respectively. The control signal input 11 is connected to an output 15 of a control loop 17 and the control signal input 13 is connected to an output 19 of a change-over switch 23 which can be operated by means of an operating device 21 and has a first input 25 connected to an output 27 of the control loop 17 and a second input 29 connected to an output 31 of an operating range limiting boundary function generator 32 which always provides a predetermined control signal corresponding to I_{test} when applied to the input 13. Consequently, when performing exposure measurements, in which the change-over switch 23 assumes the position shown, the current through the radiation source 5 is maintained at a given value I_{test} with the aid of the current control circuit 9. This circuit 9 is operative in the filament circuit of the radiation source 5 and, in the example described, this circuit cannot be adjusted sufficiently quickly to different values to make it possible to carry out a quick succession of experimental exposures at different current values. The current control circuit 9 may be formed as described in our copending U.K. Patent Application Number 43726/74, Serial No. 1486198 filed at the same date.

The voltage representing I_{test}, and originating from the output 31 of the operating range limiting boundary function generator 32, is also applied to an input 33 of an X-ray exposure meter 35 a further input 37 of which is connected to an output 39 of a radiation-sensitive element 41. The exposure meter 35 has an input 43 which is connected to an output 45 of a pulse signal source 47. A further output 46 of the pulse signal source 47 is connected to an input 49 of the voltage control circuit 7. The pulse signal source 47 ensures that a given switch-on duration of the radiation source 5 can be produced, which duration is adjustable by means of the operating device 21, and that the exposure meter 35 will be activated at the correct instant. The exposure meter 35 may receive information from the operating device, for example, about the sensitivity of a film to be used. The control voltage corresponding to V_{test} for the first exposure measurement of a sequence, is applied to the connection 15 by an output from the operating device 21, while, for subsequent exposure measurements forming part of the same sequence, the currently stored value corresponding to V_{min_n} will be employed.

After performing the first exposure measurement at a voltage V_{test} and current I_{test}, the exposure meter 35 will apply a signal to an output 51, which is proportional to the logarithm of the current value I_{w_1} which is required to provide a proposed dose or radiographic exposure density during the proposed switch-on period when associated with the voltage V_{test}. In general after performing the nth exposure measurement of a sequence, the output 51 will be proportional to the logarithm of the current value I_{w_n} and this signal will hereinafter be referred to as log I_{w_n}.

The signal log I_{w_n} is applied to a first input 53 of a summation device in the form of an adder and subtractor circuit 55. A second input 57 of this adder and subtractor circuit 55 is connected to an output 59 of a clamping circuit 61 which receives a pulse signal at an input 63 during an exposure measurement so that its output voltage is clamped to zero.

The clamping circuit 61 is fed *via* an input 65 with a signal originating from an output 67 of a current voltage function generator 69 which receives *via* an input 71, a voltage from the output 15 of the control loop 17. This input voltage is a measure of the voltage applied to the radiation source 5 and during the first exposure measurement will correspond to V_{test}. An output voltage proportional to the logarithm of the X-ray tube current value is provided at the output 67, which together with the X-ray tube voltage represented by said input voltage, would give rise to the proposed dose or radiographic exposure density after the proposed switch-on duration. The signal at the output 67 is hereinafter referred to as log I_z and that occurring during an exposure measurement will be indicated by log I'_z.

The signal log I'_z will initially appear at the output 59 of the clamping circuit 61 at the beginning of a clamp pulse input at 63 and will be shifted due to the operation of the clamping circuit 61 during the exposure measurement so that the output voltage at 59 becomes zero and a voltage $-\log I'_z$ is stored and applied in opposition to any signal log I_z subsequently applied to the input 35. This ensures that the function generated by 69 and derived from the output 59 will pass through the point which, in general after the n^{th} exposure measurement, will correspond to the current value I_{w_n} found for the corresponding test voltage value (i.e. V_{test} or V_{min_n}).

The output signal at 59 will then subsequently correspond to the difference signal

$$\log I_z - \log I'_z.$$

The adder and subtractor circuit 55 has a third input 73 which is connected to an output 75 of the operating range limiting boundary function generator 32 an input 79 of which is connected to the output 15 of the control loop 17 and thus also receives a voltage which is a measure of the voltage applied by the voltage control circuit 7 to the radiation source 5. The signal at the output 75 is arranged to be proportional to the logarithm of the limiting value of the X-ray tube current associated with that X-ray tube voltage represented by the input voltage at 79. This output signal will hereinafter be referred to as $\log I_{ng}$.

An output 81 of the adder and subtractor circuit 55 is connected *via* a switch 83 which can be operated by means of the operating device 21, to a storage circuit 85 represented in this case by a capacitor. The output 15 of the control loop 17 is connected to this capacitor 85. Immediately after an exposure measurement the switch 83 is temporarily closed and the control loop 17 is rendered operative. This control loop will then attempt to render the total input voltage of the adder and subtractor circuit 55 zero.

When the first input 53 and the second input 57 both form an additive input and the third input 73 forms a subtractive input, the combined input signals of the adder and subtractor circuit which form the output 81 is thus:—

$$\mathrm{Log}\, I_{w_n} + (\mathrm{Log}\, I_z - \mathrm{Log}\, I'_z) - \mathrm{Log}\, I_{ng}.$$

In this signal the sum of the components $\log I_{w_n}$ and $-\log I'_z$ represents the shift which must be applied to the output $\log I_z$ at 67 of the function generator 69 to cause the function to pass through the value I_{w_n} computed from measurement when the corresponding test voltage is applied to the input 71. The output 81 of the circuit 55 will be zero when the shifted signal $\log I_z + (\log I_{w_n} - \log I'_z)$ becomes equal to $\log I_{ng}$. This is the condition for a point of intersection of the function representing the limiting boundary of the operating range and the function relating tube voltage and current at a constant dose or radiographic exposure density. By the choice of the phase of the feedback in the control loop this point of intersection is chosen to correspond with the lower voltage value. The control loop then automatically provides at the output 15 that control voltage which is required to cause the voltage control circuit 7 to set the X-ray tube voltage to $V_{\min_n}$.

The above described circuit arrangement is arranged to perform on a first command from the operating device 21, a first exposure measurement with the aid of a voltage V_{test}. This is carried out by applying to the capacitor 85, prior to a series of exposure measurements, a voltage obtained from an output 87 of the operating device 21, which causes the voltage control circuit 7 to apply a voltage V_{test} to the radiation source 5. During a second exposure measurement the point corresponding to the current value I_{w_2} is found by the X-ray exposure meter while the radiation source 5 is supplied with a current I_{test} and the associated voltage value $V_{\min_1}$. The circuit of Fig. 2 will then provide $V\min_2$, and so forth. After the termination of a series of exposure measurements, the control loop 17 is interrupted by means of the switch 83 and the last value found for $V_{\min_n}$ and stored in the capacitor 85, is passed through the operating range limiting boundary function generator 32 to form at the output 75, the control voltage $\log I_{ng}$ which will provide the current value I_n for the X-ray tube. The change-over switch 23 is then set to the alternative position to that shown so that the control voltage $\log I_{ng}$ is applied to control the current control circuit 9 to supply the X-ray tube with the desired current intensity I_n.

The function generators 69 and 32 may be realized in known manner with the aid of resistors, amplifiers and diode networks.

Fig. 3 is a schematic circuit for an exposure meter 35 and uses the same reference numerals for corresponding components shown in Fig. 2.

The input 37 of the exposure meter 35 receives a current during an exposure measurement from the radiation-sensitive element 41, said current being a measure of the amount of radiation passed by an object to be examined. This current is applied through a switch 89, which is closed during the exposure measurement, to an input 91 of a difference amplifier 93 the other input of which is connected to ground. An output 95 is fed back to the input 91 *via* a capacitor 97. This amplifier constitutes, with the capacitor 97, an integration circuit and passes on the integral of the input current to an input 101 of a logarithm-forming circuit 103. The capacitor 97 is shunted by a switch 99 which discharges the capacitor 97 after each exposure measurement.

An output 105 of the circuit 103 provides a voltage which is proportional to the

logarithm of the integral of the radiation sensed by the radiation-sensitive element 41 while a voltage V_{test} and a current I_{test} are applied to the radiation source 5.

This voltage will be referred to as log E_{test}. This voltage is passed on *via* a switch 106 to a storage capacitor 107 so that it remains available after an exposure measurement. An input 109 of a subtractor circuit 111 is connected to the capacitor 107 and therefore receives continuously the voltage Log E_{test}. The voltage Log I_{test} is applied *via* terminal 33 to another input 113. This voltage is a measure of the current intensity used for the radiation source. An output of the subtractor circuit 111, applies to the output 51 of the exposure meter 35, a voltage which is proportional to

$$\text{Log } I_{test} - \text{Log } E_{test}.$$

This is arranged to represent Log I_w by an appropriate choice of circuit parameters as will be explained hereinafter.

After an exposure measurement, the voltage E_{test} obtained at the output 95 of the integrator 93, 97 satisfies the relationship $E_{test}=k\,I_{test}$ where I_{test}, as already mentioned above, is the current through the radiation source during an exposure measurement and k is a constant depending, among other things, on the subject located between the X-ray tube 5 and the radiation-sensitive element 41. For a proposed radiographic exposure density on a film, the voltage at the output 95 would have to be equal to $E_w=k\,I_w$ where I_w is the corresponding current through the radiation source 5 required to provide the desired density. The ratio

$$\frac{I_w}{I_{test}}$$

is equal to the ratio

$$\frac{E_w}{E_{test}}$$

from which it follows that

$$I_w=E_w\,.\frac{I_{test}}{E_{test}}$$

If the output voltage of the integrator is chosen to be 1 V for a proposed dose or exposure density, then $E_w=1$ and

$$I_w=\frac{I_{test}}{E_{test}}$$

and

$$\log I_w=\log I_{test}-\log E_{test}$$

which is the voltage provided at the output 51.

Fig. 4 illustrates a schematic circuit for the clamping circuit 61 and the adder and subtractor circuit 55. The input 65 of the clamping circuit 61 is connected to an input 115 of an adding circuit 117 an output 119 of which is connected to the output 59 of the clamping circuit 61 and *via* a switch 121 which is closed during an exposure measurement, to an integration circuit which is constituted by a capacitor 123 connected between an output and an input of a differential amplifier 125. The output of the latter amplifier 125 is connected to a second input 127 of the adding circuit 117.

When the switch 121 is closed the voltage at the input 127 of the adding circuit 117 will be adjusted in such a manner that the input voltage of the difference amplifier 125 becomes substantially zero so that the sum of the voltage at the input 127 and the voltage at the input 115 will thus become zero. This provides the effect of a shift to zero of a voltage value applied to the input 115 and a clamping to zero potential of the voltage at the output 119 during an exposure measurement. A charge representing $-\log I'_z$ is thus stored in the condensor 123 so that when the switch 121 is opened, an input $-\log I'_z$ is maintained at the input 127 of the adding circuit 117 to provide the appropriate shift value in conjunction with the signal log I_{w_n} applied to the input 53 to cause the function generated by 69 to pass through the measurement derived point I_{w_n} when the loop 17 is brought into operation.

The adder and subtractor circuit 55 includes an adding circuit 129 to which the inputs 53 and 57 are connected and an output 131 of which is connected through a resistor 133 to an input 135 of a difference amplifier 137. An output 139 of the difference amplifier 137 is connected to the output 81 and through a resistor 141 to the input 135. A further input 143 is connected *via* a potential divider 145, 147 to the input 73.

A voltage may be derived, if desired, from the output 131 of the adding circuit 129, since this voltage is also a measure of the desired current adjustment of the radiation source 5. In the case of this voltage, however, the store 85 is not operative because the clamping circuit is included in this circuit. The voltage at the output 139 may be used for example to detect whether, during an exposure measurement, a stable and controlled state exists in the control loop 17. When this is not the case, for example if input parameters are selected which cause the curve 2 to lie outside the limiting boundary 1, the voltage at the output 131 will exceed a predetermined value and may be used to cause

a variation in one or more parameters or for blocking the operation of the X-ray tube.

The described arrangement is very suitable for angiography.

The voltage scale used may be arbitrarily chosen. The use of a logarithmic scale for the voltage coordinate, may be advantageous since it enables the same percentage accuracy to be obtained throughout a range.

It will be evident that the method claimed can be performed not only by using mechanical or analog electrical means, but also by using digital electronic circuits. When using, for example, a computing facility with sufficient capacity, even the use of a logarithmic current scale may be unnecessary.

WHAT WE CLAIM IS:—

1. A method of controlling the magnitude of a steady voltage and a steady current applied to an X-ray tube to provide a proposed dose or radiographic exposure density as a result of a proposed exposure duration comprising the steps of applying to the X-ray tube during a predetermined test period a respective predetermined test voltage and test current within the working limits of the X-ray tube for the test period and measuring the dose or exposure value by means of an X-ray exposure meter arranged to derive therefrom a corresponding related tube operating current which together with said test voltage would provide said proposed dose or radiographic exposure density during said proposed exposure duration, mechanically or electrically forming a first function relating respective magnitudes representing a range of tube voltages and corresponding tube currents required substantially to provide said proposed dose or radiographic exposure density during said proposed exposure duration and including said test voltage and corresponding related tube operating current, mechanically or electrically forming a second function correspondingly relating respective magnitudes representing the range of tube voltages and corresponding tube currents which defines the limiting boundary of the permissible operating region of said X-ray tube for said proposed exposure duration, mechanically or electrically relating corresponding magnitudes generated by said first function and said second function to provide respective magnitudes corresponding to the lower value of the tube voltage for which said functions coincide and the corresponding tube current, and controlling the tube voltage and the tube current in correspondence therewith during a proposed exposure, or controlling the tube voltage in preparation for a further exposure determination.

2. A method as claimed in Claim 1 in which the respective magnitudes representing the tube current are made proportional to the logarithm of the tube current and said first function is caused to include said test voltage and said corresponding tube current by applying a corresponding shift to that magnitude representing the logarithm of the tube current.

3. A method as claimed in Claim 1 or Claim 2 in which a further measurement of the dose or exposure value is made with the X-ray exposure meter while applying the determined lower value of the tube voltage for which said first and second functions coincide as a result of said first measurement, and said test current to said X-ray tube, and repeating the other corresponding steps of Claim 1 to provide a further and more accurate said lower value of the tube voltage for which said functions coincide and the corresponding tube current.

4. A method of controlling the magnitude of the voltage and current applied to an X-ray tube to provide a proposed dose or radiographic exposure density as a result of a proposed exposure duration substantially as herein described with reference to the accompanying drawings.

5. X-ray apparatus arranged to carry out the method claimed in any one of Claims 1 to 4 and including a first function generator arranged to generate said first function so that an input voltage representing a proposed X-ray tube voltage gives rise to a first output signal in the form of a voltage linearly representing the logarithm of the corresponding X-ray tube current, a second function generator arranged to generate said second function so that an input voltage representing a proposed X-ray tube voltage gives rise to a second output signal in the form of a voltage linearly representing the logarithm of the corresponding limiting X-ray tube current, an X-ray exposure meter having means for sensing X-radiation after passing through an object to be radiographed and resulting from the application of a test voltage and a test current to the X-ray tube for a test period, and a circuit arranged to determine from the sensed radiation the X-ray tube current required to carry out a proposed exposure at the test voltage for a proposed exposure time and to provide a third output signal in the form of a voltage linearly representing the logarithm of the X-ray tube current so determined, a clamping circuit having a signal input to which said first output signal is supplied and a clamping input arranged to clamp the output voltage to a zero reference during a said X-ray exposure measurement, and summation means arranged to form an output voltage by summation of said second and third output signals and the output signal of said clamping circuit, the output of said summation means being applied as the input voltage to said first and second function generators and as a control input signal to a voltage control circuit for the X-ray tube, the

arrangement being such that after the completion of said X-ray exposure measurement, the output of said summation means comprises a voltage which represents the lower value of the X-ray tube voltage for which said first and second functions coincide.

6. X-ray apparatus as claimed in Claim 5 including storage means coupled to the output of said summation means to store the output signal thereof and thereby to maintain the application of said output signal to the inputs of said first and second function generators and to the X-ray tube voltage control circuit, and a change over switch arranged to control the input of an X-ray tube current control circuit so that during said X-ray exposure measurement a predetermined test current is applied to the X-ray tube and after the completion of said measurement said second output signal is employed to cause the current applied to the X-ray tube take up the magnitude of the limiting current which corresponds to said lower value of the X-ray tube voltage.

7. X-ray apparatus as claimed in Claim 6 including means for disconnecting said storage means for the output of said summation means during a first said exposure measurement and for feeding to said storage means when thus disconnected, a voltage representing the test voltage to be used during said first exposure measurement.

8. X-ray apparatus arranged to carry out the method claimed in any one of Claims 1 to 4 and including an X-ray tube, means for controlling the tube voltage and tube current of said X-ray tube, an X-ray exposure meter having X-radiation sensing means disposed behind the object to be radiographed and arranged during a test period in which the X-ray tube is energized by a test voltage and a test current within the working limits of the X-ray tube for said test period, to provide an indication of the tube current required at said test voltage to provide a proposed dose or radiographic exposure density after a proposed exposure duration, and a current-scale ruler and jig assembly comprising a current-scale ruler representing the logarithm of the tube current and associated with a limiting boundary curve representing said second function, and a jig arranged for displacement relative to said current-scale ruler in a direction parallel to the ruler representing the logarithm of the tube current, said jig carrying a curve substantially representing said first function the arrangement being such that said jig can be set so that said curve passes through a point corresponding to the test voltage and the corresponding said tube current indicated by said X-ray exposure meter and the lower value of the tube voltage at which the two curves intersect and the corresponding tube current can be read from the scale.

9. X-ray apparatus including an X-ray exposure meter and arranged to control the magnitude of the voltage and current applied to an X-ray tube substantially as herein described with reference to Figures 2 alone or in combination with Figure 3 and/or Figure 4.

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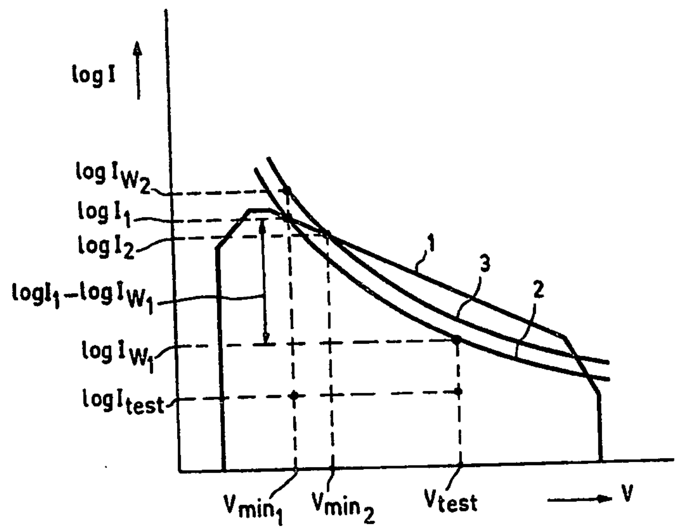
log I
log I_W2
log I_1
log I_2
logI_1 – log I_W1
log I_W1
log I_test
1
3
2
V_min1
V_min2
V_test
V

Fig.1

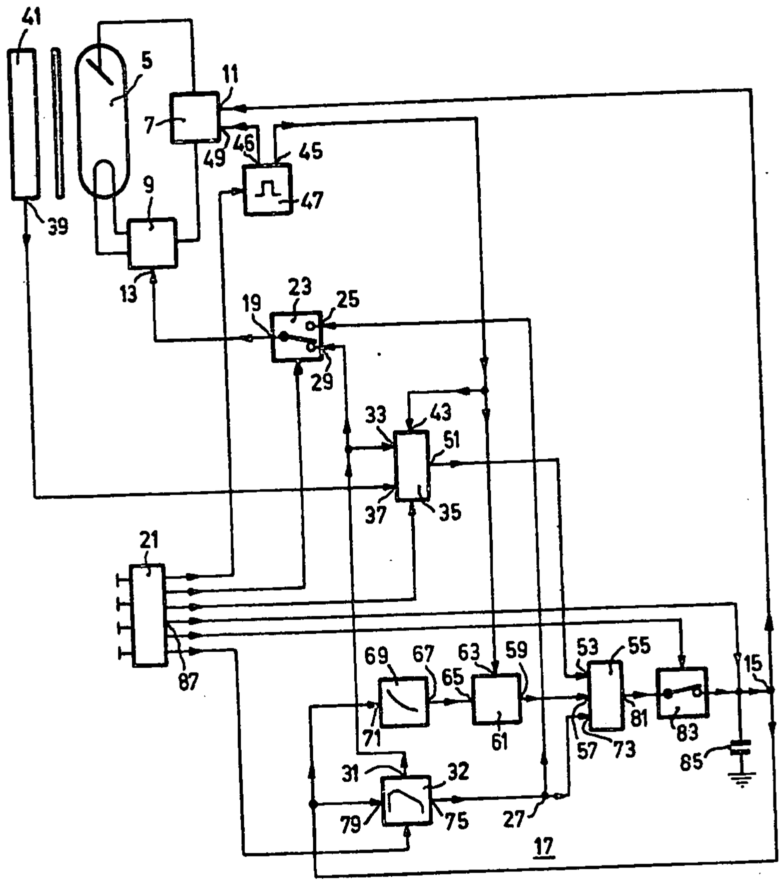
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Fig.2

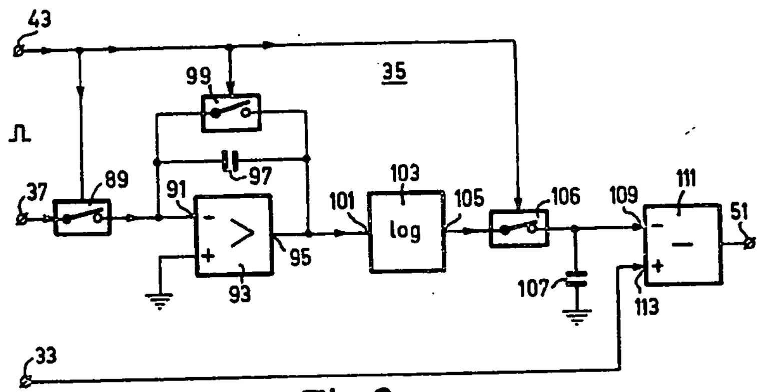
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Fig.3

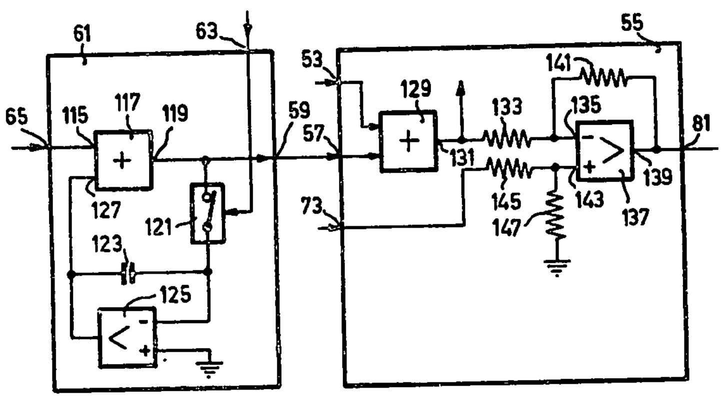
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Fig.4